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NRL Memorandum Report 2429

An Analysis of a Digital Correlation Technique for Multi-Sensor Terminal Guidance in an Air-to-Surface Missile

[Unclassified Title]

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Radar Division

April 1972

NAVAL RESEARCH LABORATORY
Washington, D.C.

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SUBJECT: An Analysis of a Digital Correlation Technique for Multi Sensor Terminal Guidance in an Air-to-Surface Missile

Background

(C) This report is part of an overall study conducted by NRL in support of the Navy's effort to develop a multi-mission fighter/attack aircraft for the 1970's. Previous experience on the F-4B, F-8U, E-2A, and F-111 weapon systems have been applied to this program.

Findings

(C) This report is specifically concerned with a map matching technique for use in the terminal guidance phase of an air-to-surface missile (ASM) trajectory. Images of known quality from flights of the AN/APQ-97 radar and AN/AAR-33 microwave radiometer were correlated for targets of varying contrast levels. System performance at the level of 26 ft. C.E.P., excluding missile airframe steering and response errors, was obtained on high contrast, large area targets, such as bri ges and airfields.

R & D Implications

(C) Reducing midcourse guidance errors to an acceptable final miss distance, is the primary purpose of the terminal sensor. This report suggests that the map matching technique appears to have the capability of reducing midcourse errors while using a missile terminal sensor which is different from the reference data sensor. This technique should be applied to various classes of terminal sensors such as radar, IR and TV to determine which sensor would be optimum for the ASM problem.

Recommanded Action

(U) In order to determine statistically valid miss distances for a variety of tactical targets, additional map matching correlations should be performed. It is recommended that simulations of the entire terminal sequence be carried out for general targets of high, medium, and low contrast backgrounds. The effects of missile airframe steering and response errors should also be included.

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Head, Tactical Analysis Section
Airborne Radar Branch

Table of Contents

Abstract	ii
Problem Status	ii
Authorization	ii
Table of Contents	iii
1.0 Introduction	1
2.0 ASM Concept	2
3.0 Terminal Position Computations	3
4.0 Reasons for Digital Simulation	5
5.0 Sample Simulation Problem	5
6.0 Results	7
7.0 Conclusions	41
References	43
Acknowledgements	44

Abstract (C)

A terminal guidance map-matching technique was evaluated on a digital computer. Imagery of known quality, from flights of the AN/APQ-97 radar and AN/AAR-33 microwave radiometer, were correlated for targets of varying contrast levels.

System performance, characterized by a C.E.P. of 26 ft. excluding missile airframe steering and response errors, was obtained on targets having large areas with high contrast, such as bridges, airfields, and boatdocks. Examples of these target classes were studied at the lowest altitude guidance stage, which determines impact C.E.P. One bridge was studied at low, middle, and high altitudes to simulate major portions of the entire terminal sequence of repeated position fixing and course correction.

Authorization

53D01-03
A-36-533/652/69F17-343-604

1.0 INTRODUCTION

(C) The Naval Research Laboratory, under a Naval Air Systems Command (NAVAIR) task, has investigated the use of multiple sensors, in combination, to acquire more information during terminal guidance of a missile than could be obtained from the same sensors used separately. In particular, an improved means of terminal guidance for tactical air-to-surface missiles (ASM) is desired. In fulfilling this task, data correlation techniques were examined to determine feasible methods of combining data from different type sensors. An unsolicited proposal from Sperry Microwave Electronics (SME) which suggested a novel method of correlating digital data, resulted in a contract for them to investigate the validity of the method and its application to map matching of data from different sensors. The study has two tasks as described below.

Task A

(U) In this task the feasibility of a map matching method utilizing a vector space linear operator was examined. This was done with a theoretical analysis and a computer simulation of the method, using digital data from an idealized target. The output of the simulation is in the form of rms, miss-distance errors which measure the effectiveness of the linear method when applied to nonlinear data. A second computer simulation examined the effectiveness of the method in reducing the errors in altitude and heading, as well as errors in latitude and longitude.

Task B

(U) This task consisted of an examination of various methods of converting the reference data into the form of the data collected in the terminal phase. The accuracy of map matching when the reference data are obtained in this manner was examined. High resolution radar (HRR) will likely be used for long-range detections in the parent aircraft. Microwave radiometer data were used for the terminal phase data. Although the radiometer is only one of a variety of sensors under consideration for the terminal phase, it was used in this study because of the availability of data.

(U) The radar cross-section of various materials was examined as well as the radiometric properties of the materials. From this study, a conversion formula was derived. A computer simulation applied the conversion formula to digital data obtained with an airborne HRR. The map-matching method was then applied in an attempt to match this converted data to data obtained with a radiometer. The output of the simulation is in the form of rms errors in position. These errors

include the effect of errors in the conversion process, errors introduced by taking the radar and radiometric data at different times, and the error in using a linear method in a non-linear situation.

(U) Task A and portions of Task B were completed and published in Ref. (1). Only a small sample of HRR data was matched to radiometric data in Ref. (1). Additional samples are necessary to achieve statistically significant results. This report presents the results of seven additional samples.

2.0 The ASM Concept

(C) A typical ASM concept is included to relate the correlation technique to the ASM problem. Either prebriefed targets or targets of opportunity are suitable in this concept. At some point along the launching aircraft flight path, a recognizable target is observed on the HRR in the aircraft. This HRR will be a synthetic aperture type operating in a forward squint mode, to provide target detections at stand-off ranges. Evasive or planned course changes can be made by the aircraft after launch.

(C) The Weapon Control officer (WCO) selects the missile impact point by placing a cursor over the target on the display of the HRR. The coordinates of the cursor position, in the aircraft reference frame, are supplied to the aircraft computer.

(C) At this point, the system proceeds automatically. Missile midcourse and terminal information is computed and supplied to the missile, which is then launched to maneuver toward the selected target independently of the aircraft. Midcourse maneuvers, controlled by an autopilot, bring the missile to the target with errors generally too large to assure target destruction. These errors should still be small enough to result in a high probability that the target will appear in the field of view (FOV) of the terminal sensor.

(C) The key element of terminal guidance is a succession of position computations obtained from the correlation technique. These yield x/y position in ground coordinates with the impact point at the origin. Each computation is followed by a steering maneuver to bring the projected flight path through the origin. Correlations are made between the stored HRR reference data and the data from the missile terminal sensor. This correlation of reference and terminal sensor data provides, in successive steps, the information necessary to reduce large midcourse errors to an acceptable impact error.

3.0 Terminal Position Computations

(C) An advanced map-matching principle is used. Information derived from a HRR image of the target area is stored in the missile in digital form before launching. In Fig. 1, T is the terrain from which the reference map is made. The array of data D is the digital reference map. Each entry in D is a number representing the radiometric temperature derived from HRR data of a small area in T_i. A linear operator (functional), derived from the entries, takes the form of two sets of real constants as listed below.

$$a_1, a_2, - - - - - a_n \qquad b_1, b_2, - - - - - b_n \tag{1}$$

(C) The process of locating the exact position of a missile with respect to the terrain, T, is as follows. A section of the terrain, T_i, is recorded by the terminal sensor. The data received by the sensor from T_i will be in a form, D_i, similar to the reference data, D, as shown below.

$$t_1, t_2, - - - - - t_n \tag{2}$$

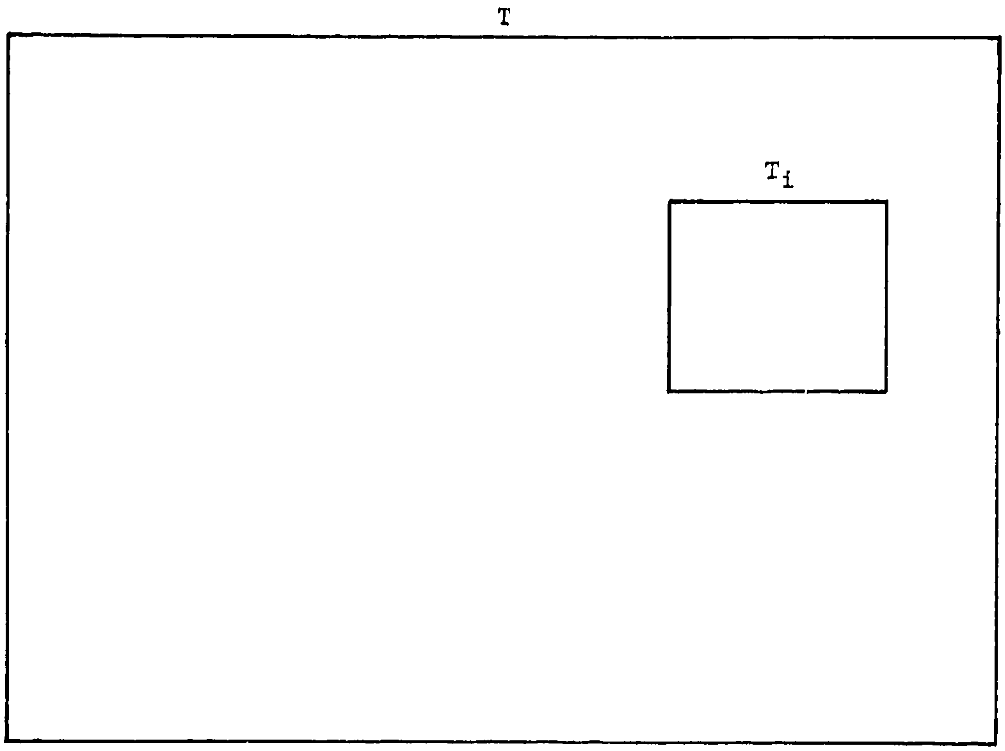
The missile position, P_i, viewing an area, T_i, is given by the complex number $Z_i = X_i + jY_i$, where X_i and Y_i are the coordinates of the projection of P_i on the plane of an arbitrary coordinate system superimposed on T. The digital entries in D_i can be thought of as a vector M_i. The map matching problem can then be viewed as the problem of finding the functional which maps the vector M_i onto the complex number Z_i. Using the information contained in the reference data, it is possible to determine the linear functional which does precisely this.

(C) It will be assumed that during the map matching process the sets of real constants derived from the radar image a_1, a_2, - - - a_n, b_1, b_2 - - - b_n have been matched to the terminal phase constants t_1, t_2, - - - t_n. The missile X, Y displacements from a true course though the impact point are simply a series of products:

$$X = a_1 t_1 + a_2 t_2 + - - - - + a_n t_n \tag{3}$$

$$Y = b_1 t_1 + b_2 t_2 + - - - - + b_n t_n \tag{4}$$

This computed result is used to steer a correction, after which a new scan is combined with a new set of matched constants c_1, c_2 - - - c_n, d_1, d_2, - - - d_n, to find a new course correction. Typically each



T- the terrain from which the reference map is made.

T_i - the terrain from which the terminal map is made.

Fig. 1 (U) - Terrain used in correlation process

corrective maneuver still results in some position error remaining, because radar and radiometer images do not correspond exactly, nor does the missile respond exactly to steering commands. Each stage, however, results in a stepwise reduction in error from the midcourse value, converging to a limiting value at impact. The derivations of the sets of constants and the linear functional used in the position computations is the subject of previous reports, Ref. (1) and (2).

4.0 Reasons for Digital Simulation

(U) Evaluation of the errors at impact can be done by analog techniques only for very simple target models as shown in Ref. 2. Experience has shown that actual target images exhibit widely varying guidance information, and consequently a wide range of impact errors. For this reason, evaluation of these errors can be facilitated by employing digital techniques for each target image. This technique is used in simulation of the terminal guidance process, starting with the radar image, performing fix computations with the radiometric image scanned by the terminal sensor, and including midcourse errors.

(U) The simulation is carried out for many values of midcourse error to evaluate performance of the system on a statistical basis. This must be done because of the irregularity in the contrast of most images. Some midcourse positions, which determine what portion of the target area is scanned, provide more contrast than others. Therefore, the impact error is highly dependent on midcourse position at the time the terminal phase begins.

5.0 Sample Simulations Problem

(U) In the data preparation stage, the desired impact point is chosen on the HRR photographic transparency. The corresponding point is located in the radiometric photographic transparency. Both X and Y coordinates are located on each image with the desired impact point at the origin. This process is performed on enlarged transparencies, to reduce the possibility of the two coordinate systems being translated or rotated relative to each other.

(U) Each target area is sampled with a densitometer, according to the diagram of Fig. 2, over an area which encompasses missile midcourse errors of $\pm 3\sigma$ in each coordinate. It was assumed in this simulation that the missile enters the terminal phase with normally distributed midcourse errors having standard deviations, σ, in each coordinate. Each scan of 121 samples covers a square $6\sigma \times 6\sigma$, centered about the missile position, and all scans cover an area, $12\sigma \times 12\sigma$. During computation, 121 scans can be taken from the array of 441 values, by successively repositioning the missile (center of scan) at unit intervals within the $6\sigma \times 6\sigma$ area.

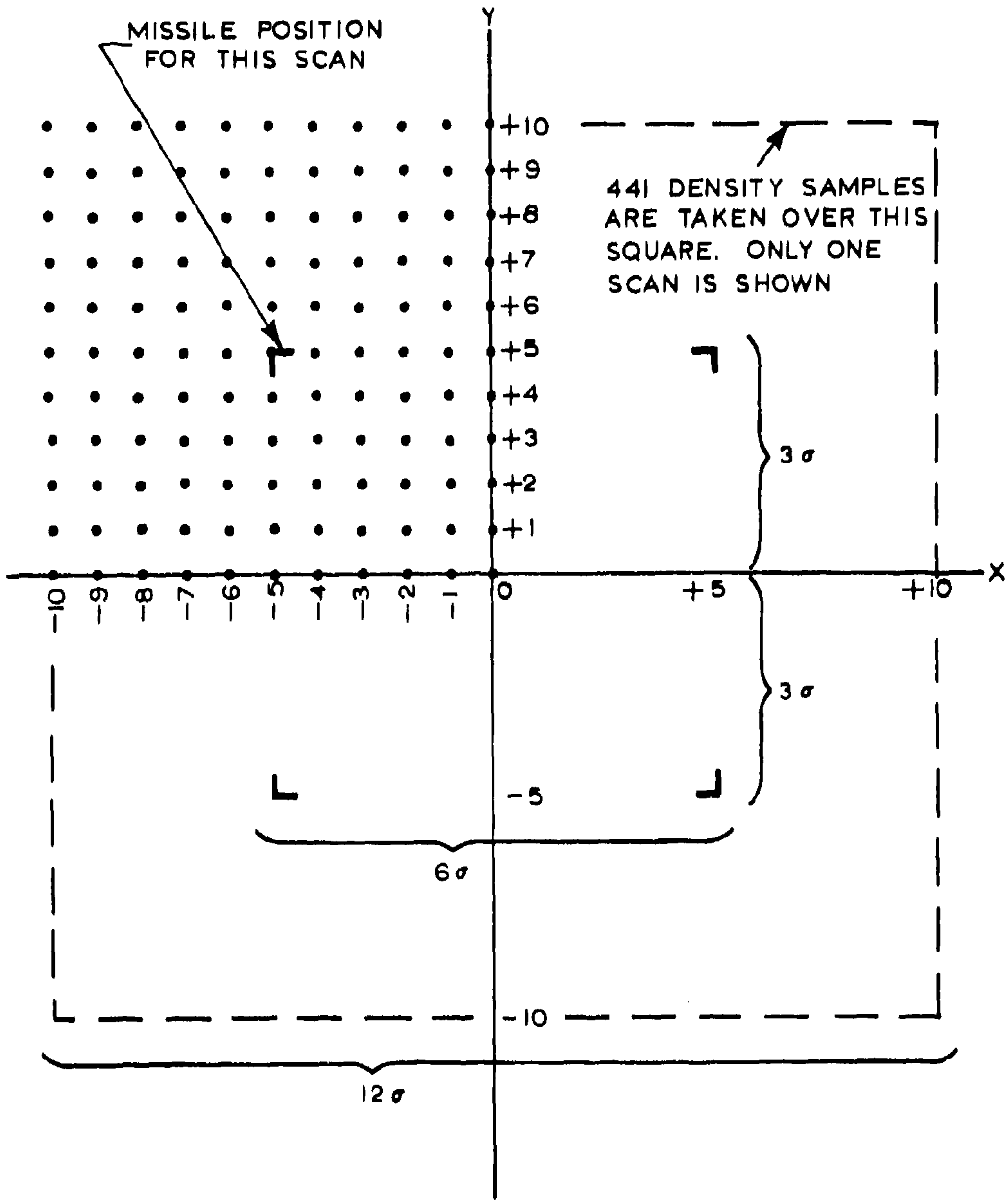


Fig. 2 (U) - Density sample locations in image

(C) The density of each transparency is quantized into eight levels, adjusted so that the range of densities coincides with the range of densities found in the $12\sigma \times 12\sigma$ area. In the first computational step, which simulates data processing before the missile is launched, radiometric temperature over the target terrain is predicted from the quantized radar data. In this case, the output of both sensors showed a linear correspondence with unity slope for most targets. It was, therefore, unnecessary to convert radar data to radiometric form, and the prediction law simply became:

Temperature image density level = radar image density level 5

The constants listed in 1 are then generated and stored in the missile.

(C) To determine the accuracy of the correlation technique many computations of position are performed. The missile is placed arbitrarily at each of the sample positions (121) in the $6\sigma \times 6\sigma$ midcourse area shown in Fig. 2. At ea position, the set of values corresponding to the radiometric i e is scanned according to the 11 x 11 scan region centered at that position. For example, Fig. 2 shows the set of samples scanned for the missile positioned at x = -5 (units), Y = +5 (units). This computation of position is repeated at all 121 midcourse sample positions, which simulates the position fixing process for all possible midcourse errors within $\pm 3\sigma$ of the impact point, assuming a typical midcourse error distribution.

(U) The output of the simulation is a tabulation of the individual x/y errors along with the probability that the missile is at a given position. The first and second moments of the set of errors are computed to generate a corrected value of σ for the particular target. This value of σ, which should be smaller than that assumed for midcourse errors, is a measure of the correlation techniques' ability to reduce midcourse error.

6.0 Results

(C) Tactical targets were chosen with a priority determined on the ease of their detectability on the imagery, as shown in Table I:

Table I

Target class	Tactical Priority
Bridges	A
Airfields	B
Road Intersections	C

Rail complex	C
Buildings	C
Factories	C
Power plants	C
Military installations	C
Petroleum storage area	C
Dock facilities	C
Dock vessels	D

The HRR imagery was collected with the AN/APQ-97 radar. The microwave radiometer images were collected with the AN/AAR-33 radiometer. All imagery was collected over the Norfolk, Virginia area. To simulate the actual missile trajectory, correlations should be performed at 4 or 5 altitudes. Due to funding limitations, the correlations were performed at only 3 altitudes for one target. This information was then used to predict the improvement that could be expected for the other correlations. A prediction of final miss distance was then generated from the 3 correlations. The remaining targets were evaluated at the lowest altitude, which is the stage that determines impact accuracy. The five targets that were evaluated in this simulation appear in Table II:

Table II

Target	Description	Altitudes of Correlation
1. Bridge #1	Bridge across Lafayette River	#1 ~ 10,000 ft. #2 ~ 5,000 ft. #3 ~ 1,000 ft.
2. Bridge #2	Bridge over the Western Branch of the Elizabeth River	1,000 ft.
3. Airfield	Patuxent River NAS	1,000 ft.
4. Rail Complex	Railroad yard in Norfolk, Va.	1,000 ft.
5. Dock	Shipping docks Norfolk, Va.	1,000 ft.

The results of the correlations are presented in Fig. 3 - 20 and Tables III - XIV in the following sequence:

- o Figures 3, 12, 15 and 18 are radar maps of various target areas.

- o Figures 4, 6, 8, 10, 13, 16 and 19 are radar maps of those targets used in the correlation calculations.

- o Figures 5, 7, 9, 11, 14, 17 and 20 are radiometric maps of targets used in the correlation calculations.

- o Table III is a sample of a digitized densitometer readings derived from the radar maps of Fig. 4 (8 density levels appear on a 0-7 scale).

- o Table IV is a smaple of a digitized densitometer reading for the radiometric maps of Fig. 5. (8 density levels appear on a 0-7 scale).

- o Table V is a sample graphic display of digitized radar densities appearing in Table III. These graphs are for illustration only. They were obtained by assigning the symbols * ; ; . ; to the range of densities 0-6 using the following code:

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6 →
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       .

0 →
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Fig. 3 (C) - High Resolution Radar Map of Norfolk Va.
Area Bridges # 1 and # 2 identified

Fig. 4 (C) - High Resolution Radar Map (High Altitude) of the Area around Bridge #1

Table III (U) – Digitalized Densitometer Readings
Obtained from Figure 4

5.	6.	6.	5.	5.	5.	2.	0.	0.	6.	6.	6.	6.	6.	6.	7.	7.	7.	7.	7.	7.
6.	6.	6.	6.	6.	7.	7.	6.	3.	0.	0.	0.	0.	0.	2.	5.	6.	7.	7.	7.	7.
6.	6.	7.	7.	7.	7.	7.	7.	6.	3.	0.	0.	0.	0.	0.	0.	2.	5.	6.	6.	7.
6.	6.	7.	7.	7.	7.	7.	7.	6.	3.	0.	0.	0.	0.	0.	0.	0.	0.	0.	4.	6.
6.	6.	6.	7.	7.	7.	7.	6.	4.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
6.	6.	6.	6.	7.	7.	6.	3.	0.	0.	0.	0.	0.	0.	3.	6.	5.	0.	0.	0.	0.
6.	6.	6.	5.	6.	6.	5.	0.	0.	0.	0.	0.	0.	3.	6.	7.	7.	6.	0.	0.	0.
5.	5.	6.	6.	2.	0.	0.	0.	0.	0.	0.	0.	3.	6.	7.	7.	7.	7.	6.	5.	6.
5.	4.	4.	4.	0.	0.	0.	0.	0.	0.	0.	4.	6.	7.	7.	7.	7.	7.	7.	7.	7.
6.	6.	5.	5.	0.	0.	0.	0.	0.	0.	4.	6.	7.	7.	7.	7.	7.	7.	7.	7.	7.
6.	6.	6.	6.	6.	4.	1.	0.	0.	0.	6.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.
7.	7.	7.	7.	6.	6.	6.	4.	2.	0.	4.	6.	7.	6.	6.	7.	7.	7.	7.	7.	7.
6.	7.	7.	6.	4.	4.	4.	2.	0.	0.	0.	5.	6.	5.	5.	6.	6.	6.	7.	7.	7.
5.	6.	5.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3.	6.	7.	7.	7.
5.	5.	5.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3.	6.	6.	7.	7.
6.	6.	6.	0.	0.	0.	0.	0.	0.	0.	4.	5.	5.	6.	6.	5.	6.	6.	6.	7.	7.
6.	6.	5.	0.	0.	0.	0.	0.	0.	2.	6.	6.	7.	7.	7.	7.	6.	6.	7.	7.	7.
6.	6.	0.	0.	0.	0.	0.	0.	0.	0.	4.	6.	6.	6.	7.	7.	7.	7.	7.	7.	7.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3.	5.	5.	5.	5.	6.	6.	6.	7.	7.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	4.	5.	6.
5.	4.	2.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

Table IV (U) - Graphic Display Prepared from the Data of Table III, Representing the Scene of Figure 4

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* ** *******. .                      ...****************** ****
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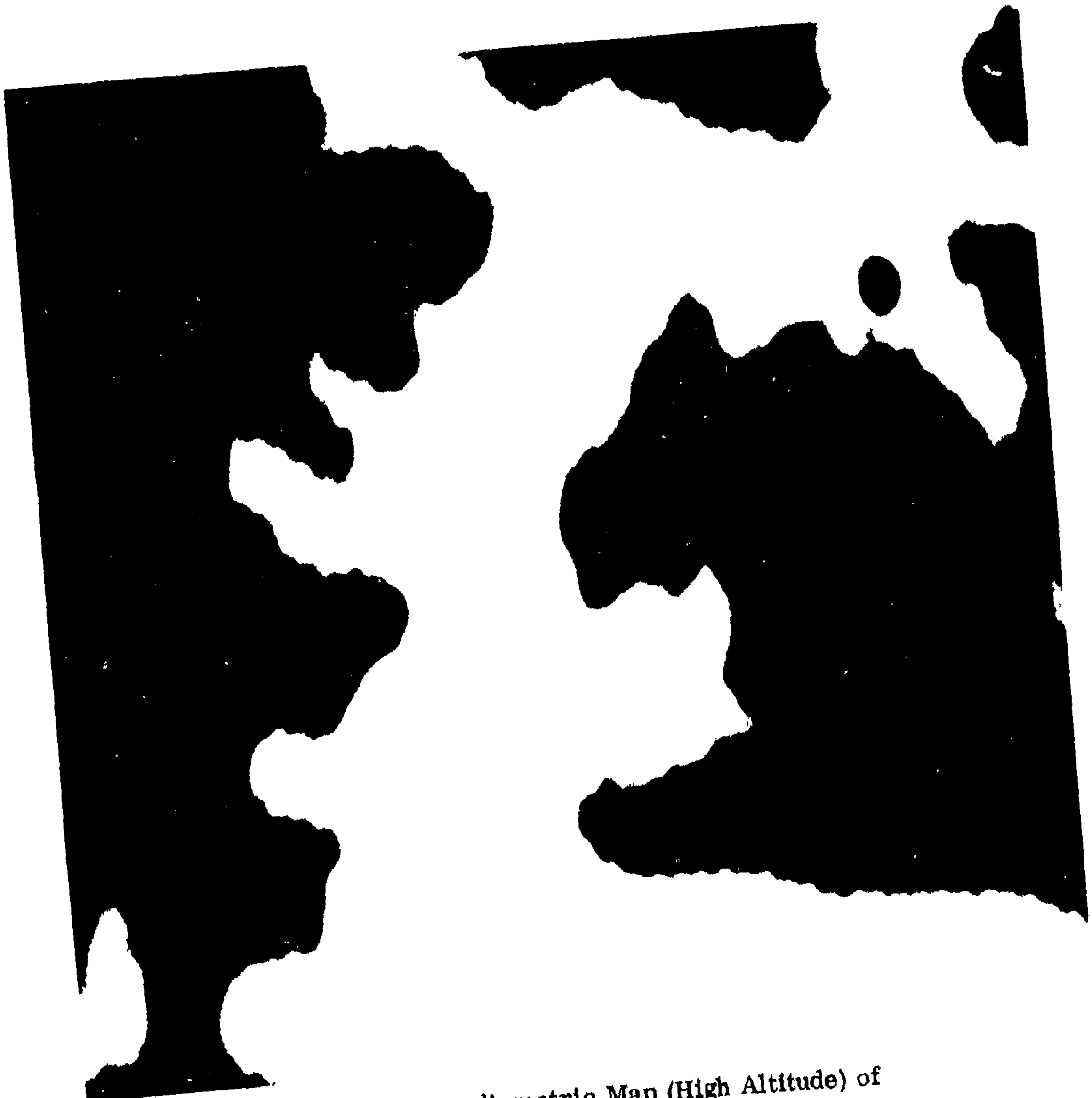

Fig. 5 (U) - Radiometric Map (High Altitude) of the Area around Bridge #1

Table V (U) - Digitalized Densitometer Readings
Obtained from Figure 5

7.	7.	7.	6.	0.	0.	1.	5.	6.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.
7.	7.	7.	7.	3.	0.	0.	0.	0.	1.	6.	7.	6.	6.	6.	7.	7.	7.	7.	7.	7.
7.	7.	7.	7.	6.	6.	6.	6.	3.	0.	0.	0.	0.	0.	0.	0.	3.	6.	7.	7.	7.
7.	7.	7.	7.	7.	7.	7.	7.	7.	5.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	2.
7.	7.	7.	7.	7.	7.	7.	7.	7.	6.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
7.	7.	7.	7.	7.	7.	7.	6.	5.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
7.	7.	7.	7.	7.	7.	6.	0.	0.	0.	0.	0.	0.	0.	0.	6.	6.	3.	0.	0.	2.
7.	7.	6.	3.	5.	6.	1.	0.	0.	0.	0.	0.	0.	3.	6.	7.	7.	6.	6.	7.	7.
5.	6.	7.	6.	0.	0.	0.	0.	0.	0.	0.	0.	0.	6.	7.	7.	7.	7.	7.	7.	7.
2.	0.	3.	3.	0.	0.	0.	0.	0.	0.	0.	6.	7.	7.	7.	7.	7.	7.	7.	7.	7.
6.	3.	0.	0.	0.	0.	0.	0.	0.	0.	5.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.
7.	7.	7.	6.	5.	0.	0.	0.	0.	0.	2.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.
7.	7.	7.	7.	7.	3.	0.	0.	0.	0.	0.	5.	5.	3.	4.	3.	6.	7.	7.	7.	7.
7.	7.	7.	6.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	6.	7.	7.	7.	7.
6.	6.	5.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	2.	6.	7.	7.	7.	7.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	4.	6.	7.	7.	7.	7.
6.	4.	0.	0.	0.	0.	0.	0.	0.	0.	4.	6.	6.	6.	7.	7.	7.	7.	7.	7.	7.
7.	6.	0.	0.	0.	0.	0.	0.	0.	0.	6.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.
7.	3.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3.	5.	6.	6.	6.	6.	7.	7.	7.	7.
3.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3.	3.
7.	7.	7.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

Table VI (U) - Graphic Display Prepared Using the Data of Table IV Representing the Scene of Figure 5

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Table VII (U) - Bridge #1 (High Altitude) Position Operator Components for Reference HRR Image

1*	-.64123257-01	.28049832-01	2*	.58870952-02	.48580057-01	3*	-.67724552-01	-.13722060-01
4*	.73250908-03	-.93256999-01	5*	-.12809686-01	.19771173&00	6*	-.40619111-01	-.12098981&00
7*	.10396975-01	-.74813040-01	8*	.26227452-01	.46129801-02	9*	.10091942-01	.79579432-01
10*	-.45282457-01	-.67218943-01	11*	-.40523196-02	-.12767008&00	12*	.15560543-01	.66743552-01
13*	-.26288653-01	.64951434-01	14*	.21085443-01	.18177589-02	15*	-.38094417-01	.21720566-01
16*	.89397104-02	-.14369124&00	17*	.34706051-01	.93317904-01	18*	-.17045531-01	.45066765-01
19*	-.16295354-02	-.46439553-01	20*	-.21885597-01	-.10000507&00	21*	.19825643-01	-.43017895-01
22*	-.97589195-02	.12210563&00	23*	-.56695690-01	-.42970154-01	24*	-.52805355-02	-.11410682&00
25*	-.37127968-02	.10916845-01	26*	.66878343-02	.12180675&00	27*	-.52979197-02	-.36157609-01
28*	.94851959-02	-.40832304-01	29*	.27115542-01	-.11885781-01	30*	-.24595619-01	-.26438854-01
31*	.14269933-01	-.17159508-01	32*	-.13764728-01	.10632771&00	33*	-.22534760-01	-.23870331&00
34*	-.28175724-02	.10216814&00	35*	-.46135542-01	-.27478188-01	36*	.65727538-02	.53642150-01
37*	.10728867-01	-.23073580-01	38*	.26337181-03	-.52753505-01	39*	.16119523-02	.64513054-01
40*	-.15000286-03	-.47090259-01	41*	.33298768-01	.27398028-01	42*	-.17853907-01	.38060250-02
43*	.82191224-02	-.68019193-01	44*	-.37880084-01	-.63640172-01	45*	-.26003748-01	-.14167786-02
46*	.87522297-02	.82428979-01	47*	-.67818020-01	-.84028901-01	48*	.16991286-01	-.11286916&00
49*	.26217876-01	.17047691&00	50*	.22718436-01	-.68384183-01	51*	.14917689-01	.42414602-01
52*	-.19074301-01	-.24802265-01	53*	.18324129-01	-.26652370-01	54*	-.25013729-01	.44682108-03
55*	.60457181-01	.69717728-01	56*	-.83749213-01	-.46356768-01	57*	-.16878460-01	-.32319018-01
58*	.33029242-01	.17223703-01	59*	-.24404055-01	.63589212-01	60*	.11292362-01	-.58648207-01
61*	.10124975-02	-.73852589-02	62*	.20314015-01	.52813318-02	63*	.31954498-01	.65598754-01
64*	-.30254516-02	.35092235-01	65*	.77032359-02	-.55221168-01	66*	.39962823-02	.62304307-01
67*	-.43110395-01	-.47622123-01	68*	-.11823250-01	-.25750346-01	69*	-.29696568-02	.22969859-01
70*	.39520210-02	-.52661196-02	71*	-.13376259-01	-.76238868-01	72*	.48364005-01	.74827445-01
73*	.16258908-01	.61354653-01	74*	.49508121-02	-.92384153-02	75*	.23435241-01	.28831646-01
76*	-.45970976-02	.15856420-02	77*	.45472880-01	.16823578-01	78*	-.33578996-01	.38816404-01
79*	-.23048508-01	.30144855-02	80*	-.52654411-02	-.24523035-01	81*	-.57546006-03	-.27236814-01
82*	.23386467-01	.39516248-01	83*	-.80646644-02	.29156661-01	84*	.14531686-01	-.24041149-01
85*	.14419850-01	-.44929519-01	86*	.11398762-01	-.69148089-02	87*	.24219760-01	.10542876&00
88*	-.13872447-02	-.49573116-01	89*	-.18290181-01	-.86695581-02	90*	.54526753-02	.36077105-01
91*	-.34627164-01	-.27294264-01	92*	.30291136-01	.10668425-01	93*	-.73835534-02	.62786743-01
94*	.24630551-01	-.93870577-01	95*	-.62614174-02	-.20577115-02	96*	.35476815-01	.80906878-01
97*	-.12329036-02	-.66601784-03	98*	.51744168-03	-.33312659-01	99*	.74438592-02	.24140649-02
100*	-.32701778-01	-.90725913-02	101*	.58747481-02	.32177581-01	102*	.27432963-01	.36290367-01
103*	-.23786236-01	-.42002256-01	104*	.23496073-01	-.65936507-02	105*	-.81606178-02	.44265643-02
106*	.51318021-01	.36850056-01	107*	-.22413932-01	.31548779-01	108*	-.47314854-02	-.88358976-01
109*	-.58979163-02	-.89916708-02	110*	.33609920-01	.71550692-01	111*	-.29901060-01	.28684556-01
112*	-.77640510-02	-.33469310-01	113*	.27245115-01	.17986806-01	114*	.19556990-01	.79412763-01
115*	.15185826-01	-.61893863-01	116*	.40221758-01	.11575211&00	117*	-.15695645-01	-.12620638-01
118*	.11123017-01	-.75411061-01	119*	.23835853-01	.12773809&00	120*	-.13668257-01	-.22939052-01
121*	-.10677568-01	-.64911707-01						

Table VIII (U) - Simulation Error Map (High Altitude) for Bridge #1

Position 1	Position 2	Position 3	Position 4	Position 5	Position 6	Position 7	Position 8	Position 9	Position 10	Position 11
X_1 = -2,15 Y_1 = 4,97 P_1 = ,71-05	X_2 = -1,71 Y_2 = 4,48 P_2 = ,36-04	X_3 = -,56 X_4 = 5,91 P_4 = ,13-03	,82 6,54 ,31-03	1,42 6,71 ,53-03	1,88 5,24 ,64-03	2,33 7,40 ,53-03	3,46 6,29 ,31-03	3,58 5,92 ,13-03	3,74 4,96 ,36-04	4,12 4,16 ,71-05
Position 12 X_{12} = -2,57 Y_{12} = 4,60 P_{12} = ,36-04	Position 13 X_{13} = -,92 Y_{13} = 5,00 P_{13} = ,18-03	-,46 4,02 ,64-03	,20 4,39 ,16-02	,32 4,22 ,27-02	1,14 4,54 ,32-02	1,19 2,60 ,27-02	1,23 2,81 ,16-02	1,75 2,77 ,64-03	1,98 1,95 ,18-03	3,38 3,25 ,36-04
Position 23 X_{23} = -2,90 Y_{23} = 2,77 P_{23} = ,13-03	-1,38 3,74 ,64-03	-,12 1,92 ,22-02	-,09 1,16 ,55-02	,66 1,59 ,95-02	,37 1,20 ,11-01	,47 -,56 ,95-02	,51 1,35 ,55-02	1,17 1,25 ,22-02	1,27 1,17 ,64-03	2,10 1,92 ,13-03
Position 34 -2,16 1,40 ,31-03	-1,98 ,63 ,16-02	-,37 2,25 ,55-02	,13 ,26 ,14-01	-,23 -1,00 ,23-01	,39 -,50 ,28-01	,10 -,22 ,23-01	,57 -,12 ,14-01	,68 -1,02 ,55-02	1,11 -,35 ,16-02	2,13 -,63 ,31-03
Position 45 -1,89 1,06 ,53-03	-1,45 -,67 ,27-02	-,75 -1,24 ,95-02	-,20 -,76 ,23-01	-,12 -,86 ,40-01	-,13 -,62 ,48-01	,25 [illegible] ,40-01	,41 -1,21 ,23-01	,78 -1,03 ,95-02	1,60 -,67 ,27-02	2,25 ,48 ,53-03
Position 56 -1,91 ,00 ,64-03	-1,38 -,77 ,32-02	-,72 -2,20 ,11-01	-,46 -1,80 ,28-01	-,24 -,17 ,48-01	,12 -1,23 ,57-01	-,16 -,95 ,48-01	,26 -,80 ,28-01	,82 ,71 ,11-01	1,66 1,31 ,32-02	2,86 -,56 ,64-03
Position 67 -2,08 -1,52 ,53-03	-,66 -,59 ,27-02	-,34 -1,13 ,95-02	,21 ,20 ,23-01	,06 -1,54 ,40-01	-,06 -1,18 ,48-01	-,15 -,78 ,40-01	,00 -,19 ,23-01	,69 -,81 ,95-02	,81 -1,21 ,27-02	2,78 ,10 ,53-03
Position 78 -1,37 -3,52 ,31-03	-1,24 -1,85 ,16-02	-,42 -,72 ,55-02	-,46 -,95 ,14-01	-,05 -,42 ,23-01	-,00 -,49 ,28-01	-,34 ,41 ,23-01	,10 -,14 ,14-01	,35 -1,47 ,55-02	1,52 -,89 ,16-02	2,97 -1,07 ,31-03
Position 89 -1,98 -2,12 ,13-03	-1,22 -2,65 ,64-03	-,76 -2,08 ,22-02	-,25 -1,33 ,55-02	-,86 -,58 ,95-02	-,10 ,25 ,11-01	-,45 -1,35 ,95-02	-,06 -1,14 ,55-02	,86 -,64 ,22-02	1,84 -1,28 ,64-03	3,34 -2,44 ,13-03
Position 100 -2,35 -3,80 ,36-04	-1,64 -2,41 ,18-03	-1,23 -1,94 ,64-03	-,90 -1,56 ,16-02	-,62 -2,07 ,27-02	-,98 -1,57 ,32-02	-,30 -1,01 ,27-02	,53 -1,82 ,16-02	1,53 -1,37 ,64-03	2,86 -2,32 ,18-03	4,08 -3,07 ,36-04
Position 111 -2,60 -5,33 ,71-05	-2,16 -5,82 ,36-04	-2,14 -5,17 ,13-03	-1,98 -4,14 ,31-03	-1,42 -2,73 ,53-03	-,87 -4,01 ,64-03	-,45 -3,81 ,53-03	,73 -2,31 ,31-03	2,00 -3,00 ,13-03	2,94 -3,90 ,36-04	4,59 -3,56 ,71-05

|← 1 unit →|

X1M(1) = -,018 units

X1M(2) = -,542 units

X2M(1) = ,244 units^2

X2M(2) = 1,286 units^2

S = ,875 units

S = 263 ft

C.E.P. = 309 ft

Position in units, on the ground
1 unit = 300 ft
Midcourse σ = 500 ft
Ground coordinate origin circled

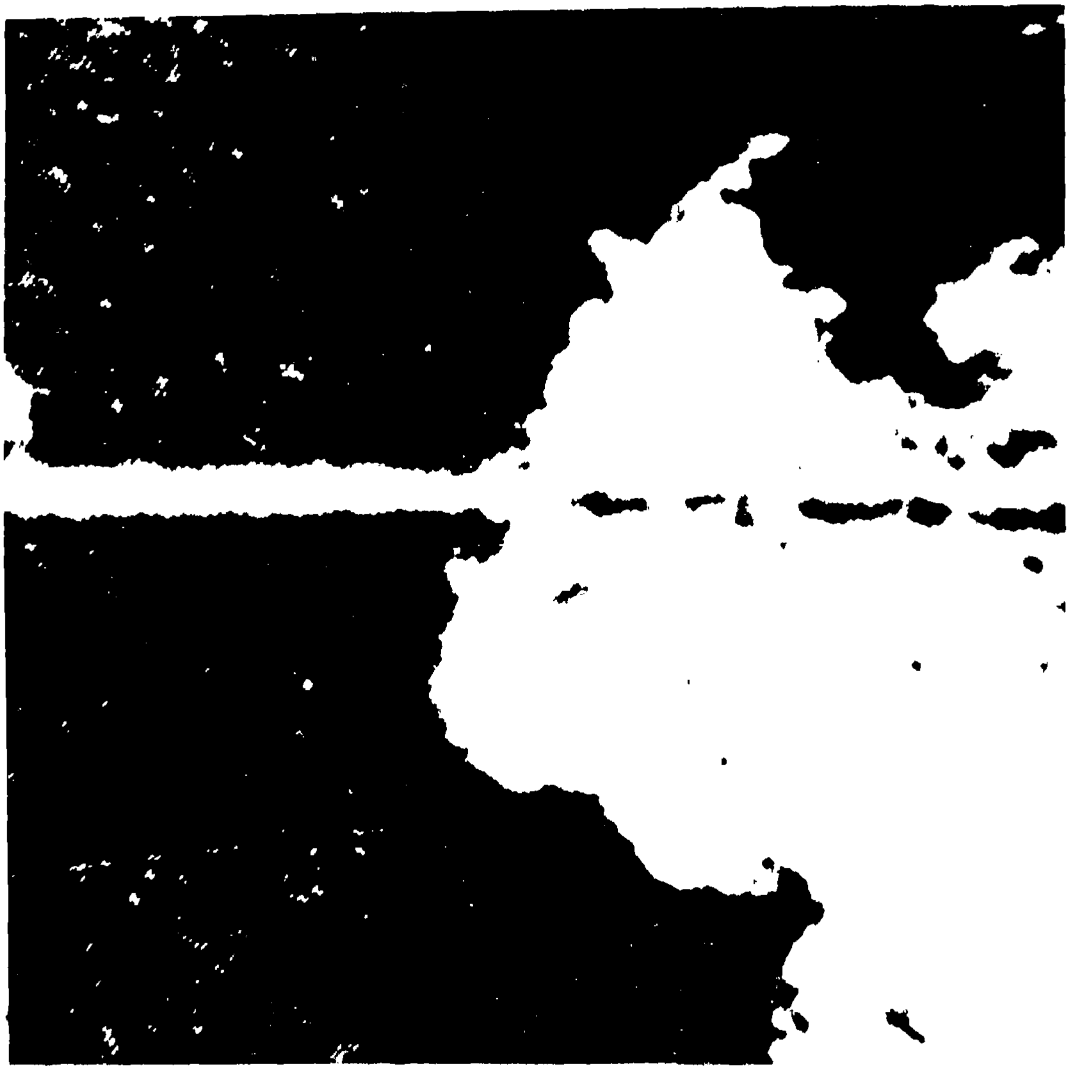

Fig. 6 (C) - High Resolution Radar Map (Medium Altitude) of the Area around Bridge #1

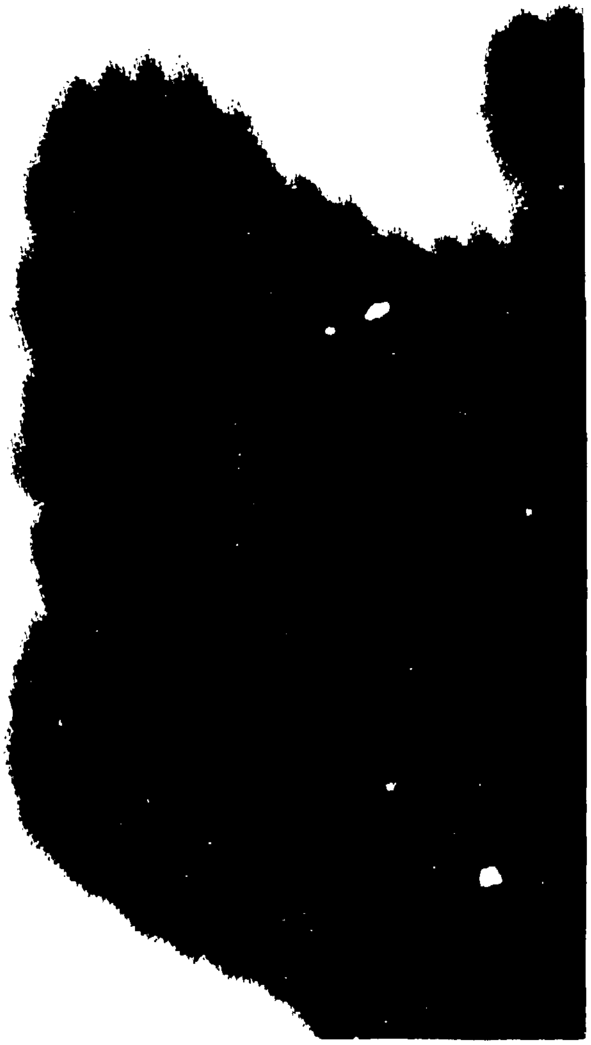

Fig. 7 (U) - Radiometric Map (Medium Altitude) of the Area around Bridge #1

Table IX (U) - Simulation Error Map (Medium Altitude) for Bridge #1

-4.32 4.80 .71-05	-2.08 4.03 .36-04	.03 4.07 .13-03	.46 2.83 .31-03	.57 2.36 .53-03	.12 1.36 .64-03	.37 1.54 .53-03	1.04 2.43 .31-03	1.39 2.68 .13-03	1.63 2.18 .36-04	2.62 1.77 .71-05
-4.24 3.84 .36-04	-1.53 3.74 .18-03	.02 2.63 .64-03	.75 2.53 .16-02	.62 1.88 .27-02	.50 1.63 .32-02	.15 .69 .27-02	.33 .50 .16-02	1.30 2.45 .64-03	1.93 2.62 .18-03	2.83 2.33 .36-04
-4.09 2.95 .13-03	-1.54 2.15 .64-03	.33 2.72 .22-02	.85 2.15 .55-02	.90 1.94 .95-02	.50 1.04 .11-01	.25 .89 .95-02	.50 1.34 .55-02	.08 .12 .22-02	1.09 .95 .64-03	2.20 1.89 .13-03
-4.15 1.41 .31-03	-1.23 1.86 .16-02	.55 2.19 .55-02	1.07 1.98 .14-01	1.02 1.97 .23-01	.45 1.33 .28-01	.31 1.21 .23-01	.42 1.20 .14-01	1.00 2.53 .55-02	.94 1.23 .16-02	1.58 1.64 .31-03
-3.77 .84 .53-03	-.82 1.52 .27-02	.57 1.65 .95-02	.76 1.13 .23-01	.76 1.46 .40-01	.27 1.27 .48-01	.03 .97 .40-01	.37 1.91 .23-01	.17 1.10 .95-02	.73 1.51 .27-02	1.29 2.12 .53-03
-3.70 -.40 .64-03	-.75 .77 .32-02	.58 .93 .11-01	1.02 1.50 .28-01	.50 1.07 .48-01	-.12 .57 .57-01	-.15 1.13 .48-01	-.04 1.64 .28-01	.40 2.80 .11-01	.82 2.38 .32-02	1.05 2.32 .64-03
-3.07 .18 .53-03	-.72 .07 .27-02	.51 .26 .95-02	.92 .67 .23-01	.40 .38 .40-01	.13 .60 .48-01	-.17 .84 .40-01	-.26 1.13 .23-01	-.34 .88 .95-02	.72 2.30 .27-02	.80 1.83 .53-03
-3.42 -1.26 .31-03	-.69 .15 .16-02	.45 .44 .55-02	.58 -.19 .14-01	.69 .41 .23-01	.23 .00 .28-01	.27 .91 .23-01	.23 1.46 .14-01	.01 1.13 .55-02	.42 1.26 .16-02	1.16 2.20 .31-03
-3.65 -2.08 .13-03	-1.31 -1.08 .64-03	-.17 -.60 .22-02	.63 .64 .55-02	.67 .33 .95-02	.62 .51 .11-01	.40 .32 .95-02	.52 .94 .55-02	.86 1.65 .22-02	1.16 1.62 .64-03	1.17 .56 .13-03
-3.99 -3.42 .36-04	-1.98 -2.07 .18-03	-.67 -.99 .64-03	-.17 -1.09 .16-02	.45 -.50 .27-02	.91 .94 .32-02	.85 .75 .27-02	.93 .78 .16-02	1.05 .69 .64-03	1.46 .71 .18-03	2.53 1.85 .36-04
-4.22 -4.44 .71-05	-2.75 -3.32 .36-04	-1.40 -2.41 .13-03	-.44 -.99 .31-03	.19 -.53 .53-03	.31 -1.04 .64-03	1.06 .28 .53-03	1.30 .80 .31-03	1.66 .99 .13-03	2.21 .91 .36-04	2.36 -.50 .71-05

← 1 unit →

X1M(1) = .333 units   X2M(1) = .315 units^2 S = .943 units   1 unit = 125 ft

S = 118 ft

X1M(2) = 1.046 units   X2M(2) = 1.462 units^2 C.E.P. = 139 ft   Previous Stage σ (assumed) = 208 ft

Fig. 8 (C) - High Resolution Radar Map (Low Altitude) of the Area around Bridge #1

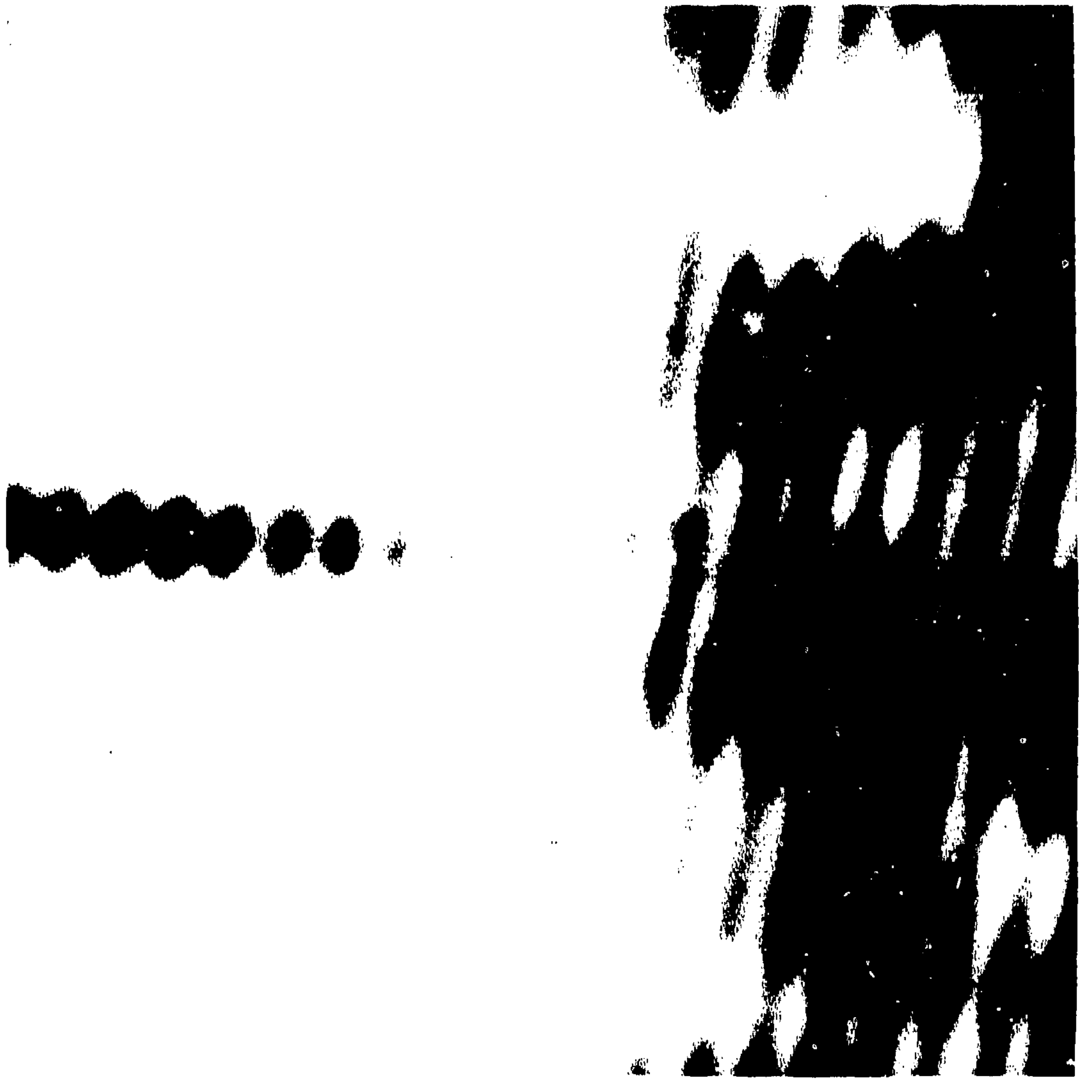

Fig. 9 (U) - Radiometric Map (Low Altitude) of the Area around Bridge #1

Table X (U) - Simulation Error Map (Low Altitude) for the Area Around Bridge #1

-6.31 2.50 .71-05	-4.85 2.71 .36-04	-3.50 2.81 .13-03	-1.73 2.85 .31-03	-.80 3.02 .53-03	.19 3.26 .64-03	.87 3.51 .53-03	.98 3.90 .31-03	.89 4.02 .13-03	.89 4.15 .36-04	2.05 3.96 .71-05
-5.06 .95 .36-04	-4.23 1.15 .18-03	-2.54 1.33 .64-03	-.50 1.23 .16-02	.16 1.35 .27-02	1.38 1.47 .32-02	1.11 2.02 .27-02	1.51 2.42 .16-02	1.73 2.51 .64-03	1.70 2.61 .18-03	2.77 2.75 .36-04
-3.79 .41 .13-03	-2.21 .53 .64-03	-.41 .49 .22-02	.71 .40 .55-02	1.46 .50 .95-02	2.03 .69 .11-01	1.84 1.18 .95-02	1.99 1.53 .55-02	1.11 1.79 .22-02	1.94 1.93 .64-03	2.41 1.93 .13-03
-3.43 .48 .31-03	-1.73 .45 .16-02	-.08 .33 .55-02	.66 .30 .14-01	1.38 .15 .23-01	1.31 .49 .28-01	1.45 .71 .23-01	.97 .97 .14-01	.84 1.25 .55-02	1.14 1.34 .16-02	1.56 1.34 .31-03
-4.36 .51 .53-03	-2.81 .47 .27-02	-1.19 .42 .95-02	.26 .10 .23-01	.83 .12 .40-01	.41 .36 .48-01	.83 .40 .40-01	.08 .72 .23-01	.64 .77 .95-02	.23 .79 .27-02	1.35 .75 .53-03
-4.49 .44 .64-03	-3.37 .29 .32-02	-1.63 .19 .11-01	-.34 .03 .28-01	.28 -.03 .48-01	.62 -.05 .57-01	.38 .05 .48-01	.00 .31 .28-01	-.19 .10 .11-01	.08 .14 .32-02	1.03 .07 .64-03
-4.51 .00 .53-03	-3.78 -.15 .27-02	-1.45 -.24 .95-02	-.34 -.29 .23-01	.14 -.39 .40-01	1.05 -.47 .48-01	.49 -.44 .40-01	.33 -.51 .23-01	-.21 -.34 .95-02	.15 -.36 .27-02	1.30 -.58 .53-03
-4.08 -.41 .31-03	-3.33 -.50 .16-02	-1.69 -.56 .55-02	.14 -.80 .14-01	.82 -.93 .23-01	1.10 -.82 .28-01	.91 -.93 .23-01	.63 -1.09 .14-01	.30 -1.12 .55-02	.78 -1.11 .16-02	1.04 -1.19 .31-03
-4.80 -.62 .13-03	-3.25 -.95 .64-03	-1.66 -.95 .22-02	-.09 -1.16 .55-02	1.07 -1.31 .96-02	1.12 -1.38 .11-01	1.34 -1.54 .95-02	.58 -1.69 .55-02	.40 -1.66 .22-02	.51 -1.79 .64-03	1.57 -1.95 .13-03
-5.77 -1.52 .36-04	-4.28 -1.74 .18-03	-2.48 -1.70 .64-03	-1.04 -1.90 .16-02	.41 -2.01 .27-02	.51 -2.19 .32-02	.85 -2.24 .27-02	.45 -2.25 .16-02	.23 -2.49 .64-03	.42 -2.65 .18-03	1.21 -2.93 .36-04
-5.69 -3.01 .71-05	-4.81 -3.13 .36-04	-3.04 -3.27 .13-03	-1.52 -3.34 .31-03	-.75 -3.33 .53-03	.33 -3.44 .64-03	.45 -3.46 .53-03	.14 -3.66 .31-03	.36 -3.59 .13-03	.49 -3.73 .36-04	1.36 -3.89 .71-05

|◄1 unit►|

X1M(1) = .462 units   X2M(1) = .903 units^2 S = .843 units   1 unit = 21 ft
S = 18 ft
X1M(2) = -.068 units   X2M(2) = .520 units^2 C.E.P. = 21 ft   Previous Stage σ (assumed) = 35 ft

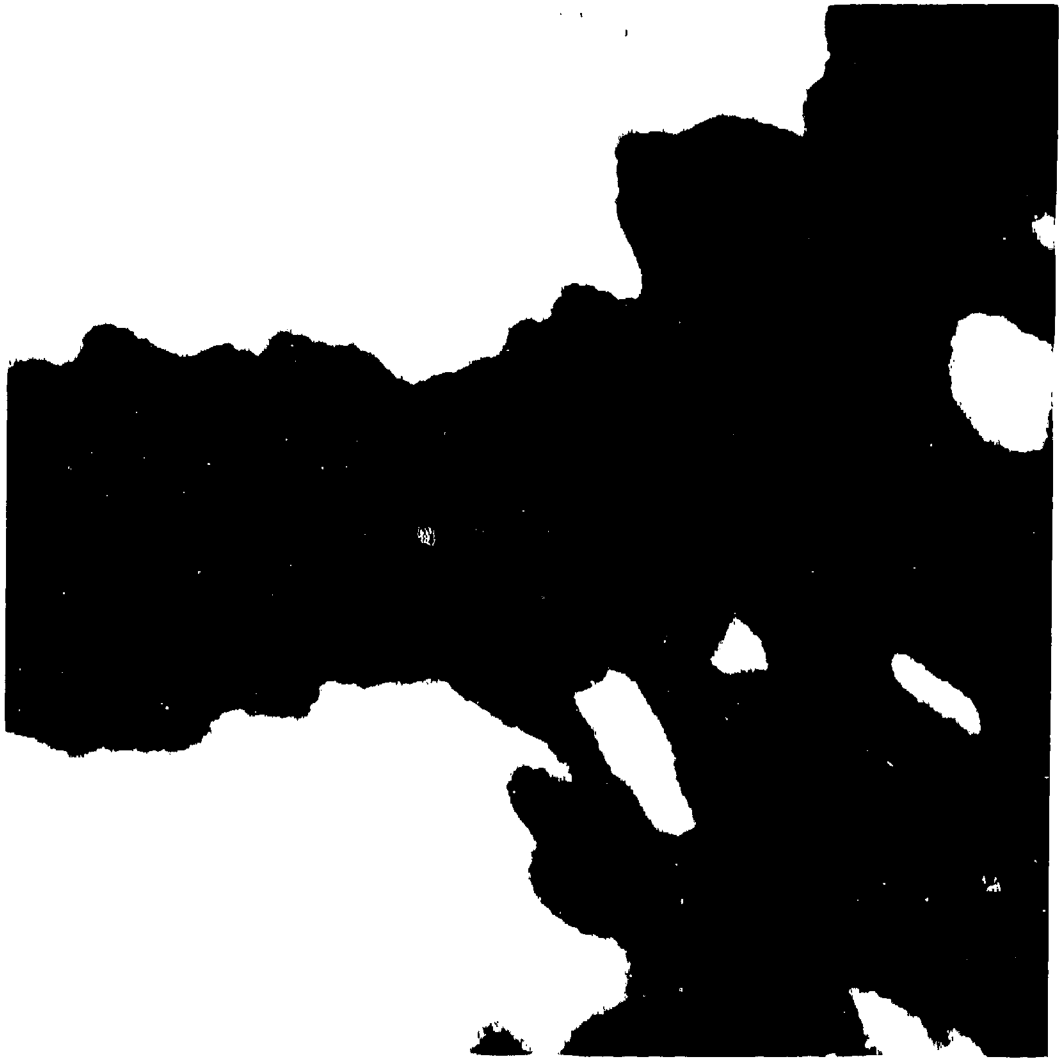

Fig. 10 (C) - High Resolution Radar Map (Low Altitude) of the Area around Bridge #2

Fig. 11 (U) - Radiometric Map (Low Altitude) of the Area around Bridge #2

Table XI (U) - Simulation Error Map (Low Altitude) for Bridge #2

-7.05 3.28	-5.94 3.07	-4.83 2.66	-2.67 2.85	-.99 2.38	-.51 2.07	.68 2.27	1.39 2.23	.71 1.91	1.74 2.32	2.63 2.35
-7.14 1.83	-5.99 1.02	-3.57 1.16	-1.76 .80	-1.09 .53	.08 .76	1.20 .88	.87 .67	1.56 1.08	2.00 1.17	2.66 1.35
-7.16 .28	-4.55 -.02	-2.08 -.18	-1.09 -.29	-.58 -.21	1.02 .04	.61 -.17	.44 -.08	1.07 .35	2.08 .48	2.69 1.02
-5.46 .13	-3.23 -.41	-1.41 -.51	-.66 -.55	.71 -.11	.27 -.38	-.16 -.45	.65 .10	.73 -.11	1.09 .13	2.46 .65
-3.68 .32	-1.99 -.14	-1.27 -.40	.45 -.01	.82 -.05	.14 -.35	.84 .15	.39 -.21	-.10 -.38	.98 .30	2.94 .63
-3.42 .27	-1.80 .21	-.45 .06	.98 .32	.95 -.18	.89 .04	1.10 -.05	.29 -.29	.86 .03	1.52 -.04	1.85 -.06
-3.68 .28	-2.21 .41	-.91 .24	.05 .22	1.35 .64	1.87 .38	.87 .13	1.72 .60	1.66 .31	2.02 .17	2.62 -.22
-5.11 -.53	-3.10 .33	-1.32 .41	-.05 .79	.78 .36	.87 .47	1.46 .53	1.51 .42	1.11 .09	1.59 -.16	2.91 -.30
-5.28 -1.00	-4.25 -.32	-2.14 .60	-1.01 .21	-.29 .25	.92 .56	.96 .40	.95 .02	1.04 -.35	1.34 -.69	1.97 -1.22
-5.83 -2.00	-4.37 -1.38	-3.70 -1.13	-2.18 -.46	-.70 -.60	-.14 -.55	.11 -.83	-.49 -1.32	.53 -1.34	1.15 -1.84	1.23 -2.39
-6.74 -3.45	-4.54 -2.71	-3.85 -2.54	-2.64 -2.18	-1.18 -1.87	-1.12 -2.42	-.69 -2.46	-.23 -2.70	.00 -3.32	.69 -3.48	2.02 -3.89

← 1 unit →

	S = .809 units
X1M(1) = .594 units	S = 20 ft
X1M(2) = .073 units	C.E.P. = 24 ft
X2M(1) = 1.153 units^2	1 unit = 25 ft
X2M(2) = .156 units^2	Previous Stage σ (assumed) = 42 ft

Fig. 12 (C) - High Resolution Radar Map (High Altitude) of Airfield

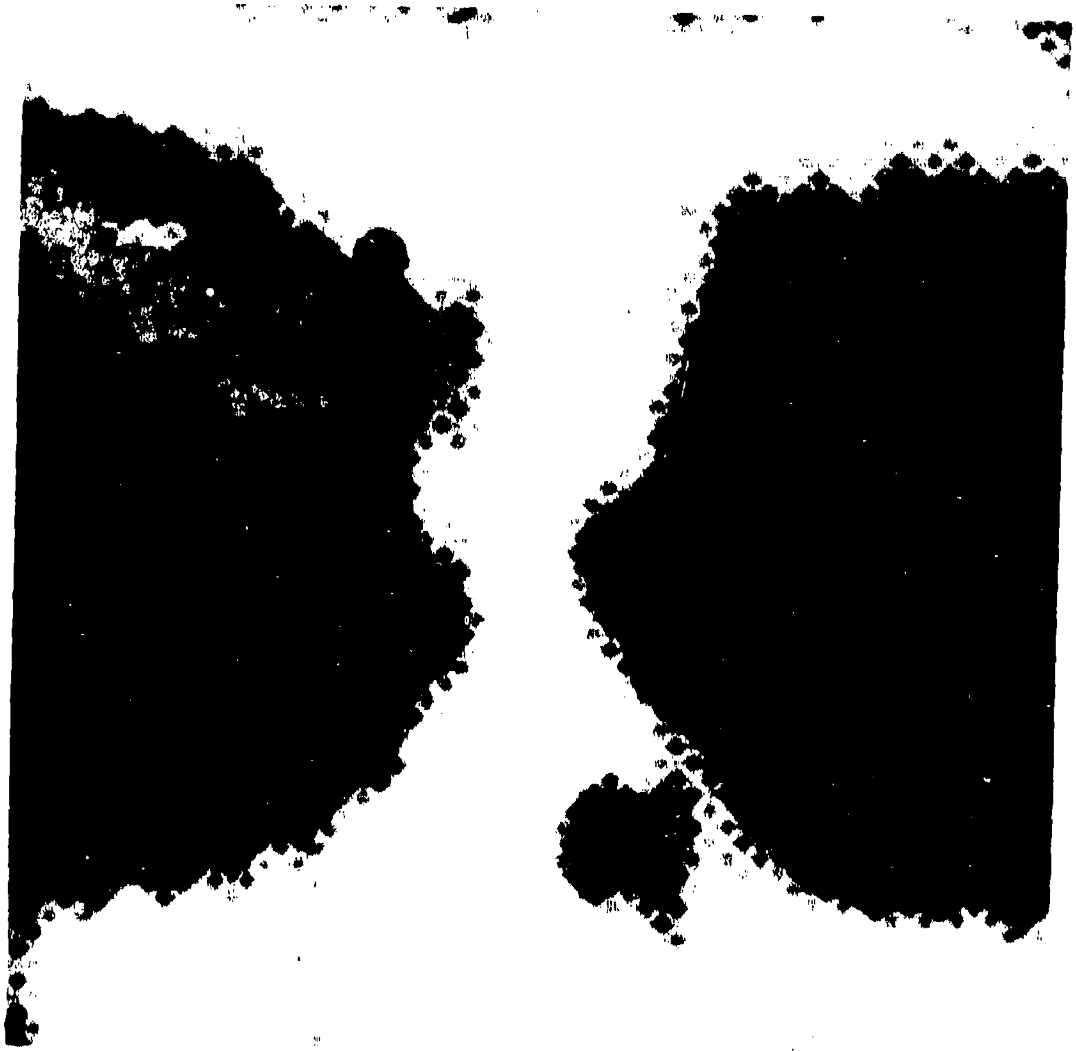

Fig. 13 (C) - High Resolution Radar Map (Low Altitude) of Airfield

Fig. 14 (U) - Radiometric Map (Low Altitude)
of Airfield

Table XII (U) - Simulation Error Map (Low Altitude) for Airfield

-3.81 1.91	-2.64 2.38	-1.88 2.38	-1.76 2.29	-1.40 2.30	-1.31 2.19	-1.07 2.48	-.28 2.90	.62 2.94	1.31 2.72	2.51 2.38
-3.47 -.15	-2.20 -.03	-1.37 .07	-1.56 -.00	-1.21 .11	-1.55 .02	-1.22 .18	-.62 .52	-.15 .70	.99 .99	2.07 .54
-2.83 -1.14	-1.67 -.92	-1.54 -1.17	-1.16 -1.03	-1.50 -1.16	-1.41 -.88	-1.33 -.99	-1.05 -.55	-.30 -.32	.77 .12	1.53 -.44
-2.22 -1.35	-1.37 -1.26	-1.21 -1.22	-.85 -1.03	-1.73 -1.34	-1.37 -1.28	-1.14 -1.00	-.98 -.61	-.17 -.07	.17 .10	1.23 -.36
-1.77 -1.13	-1.49 -1.51	-.39 -1.30	-1.18 -1.03	-1.42 -1.05	-1.13 -.86	-1.50 -.95	-.68 -.56	-.05 -.20	-.15 -.25	1.40 -.26
-1.90 -1.10	-.71 -1.16	-.45 -.96	-1.09 -1.01	-.79 -.51	-1.29 -.82	-.73 -.36	-.44 -.49	-.53 -.47	.25 -.13	1.63 -.15
-1.56 -.83	-.48 -.91	-.50 -.81	-.61 -.50	-.89 -.37	-.96 -.45	-.21 -.28	-.29 -.37	-.26 -.22	.46 -.25	1.93 -.06
-1.64 -1.09	-.58 -.76	-.75 -.77	-.47 -.64	-.83 -.40	-.54 -.31	-.21 -.28	-.52 -.30	.25 -.30	1.04 -.02	1.80 -.20
-1.73 -1.19	-1.06 -1.10	-.68 -.84	-.68 -.49	-.67 -.38	-.31 -.46	-.40 -.52	-.03 -.23	.56 -.39	1.28 -.36	2.34 -.27
-1.77 -1.44	-1.56 -1.41	-1.01 -1.12	-.76 -.86	-.52 -.75	-.26 -.77	-.16 -.78	.49 -.79	.99 -.68	1.67 -.71	3.03 -.37
-2.20 -2.08	-1.51 -1.65	-1.31 -1.72	-.90 -1.86	-.20 -1.60	-.18 -1.53	.49 -1.26	.85 -1.57	1.34 -1.30	2.15 -1.45	3.58 -.78

|← 1 unit →|

X1M(1) = -.838 units
X1M(2) = -.649 units
X2M(1) = .942 units^2
X2M(2) = .566 units^2

S = .868 units
S = 22 ft
C.E.P. = 26 ft
1 unit = 25 ft
Previous Stage σ (assumed) = 42 ft

Fig. 15 (C) - High Resolution Radar Map of Norfolk, Va. Area with a Rail Complex indicated by an Arrow.

Fig. 16 (C) - High Resolution Radar Map (Low Altitude) showing the same Rail Complex indicated in Figure 15.

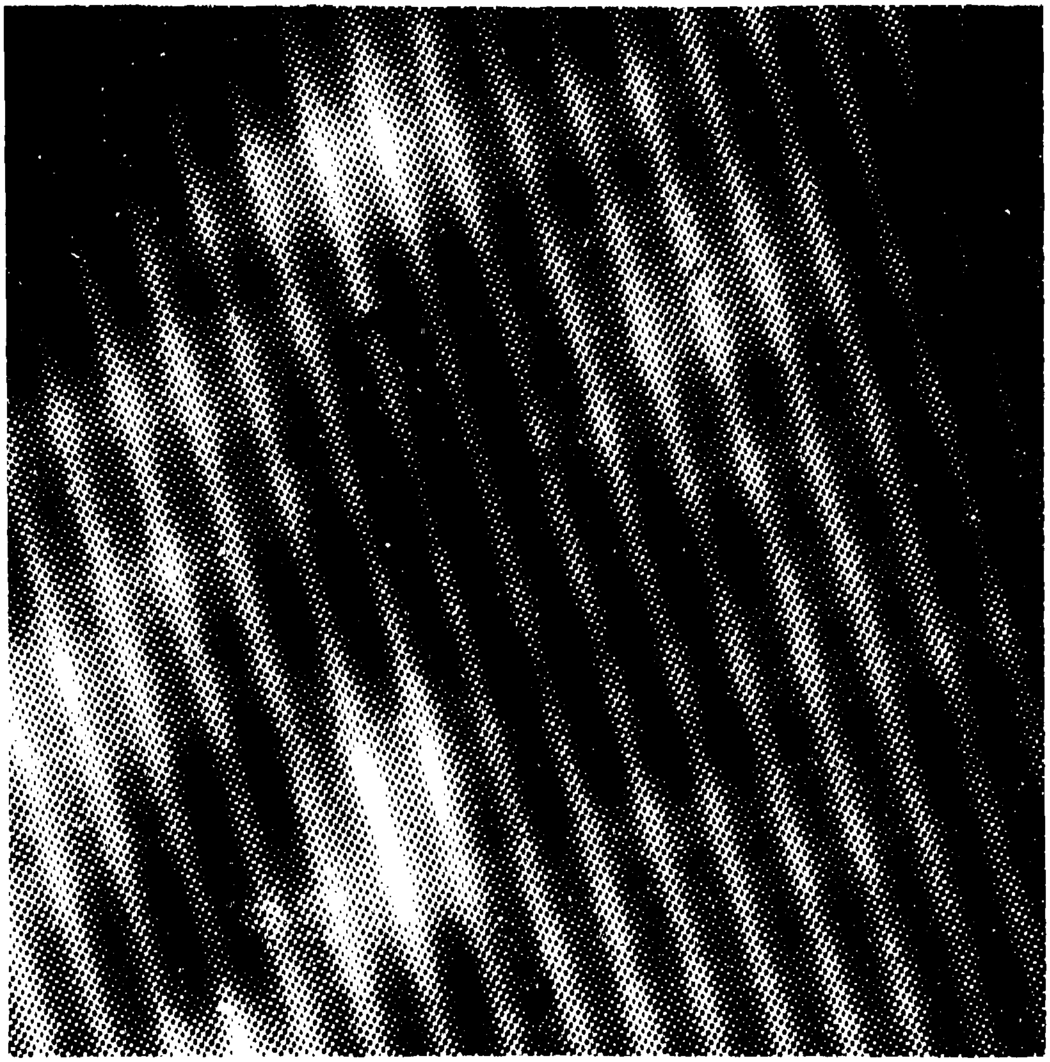

Fig. 17 (U) - Radiometric Map (Low Altitude) showing the same Rail Complex as that shown in Figures 15 and 16.

Table XIII (U) - Simulation Error Map (Low Altitude) for Rail Complex

-5.28 7.09 .71-05	-2.05 7.02 .36-04	-1.21 6.11 .13-03	-1.99 5.78 .31-03	-.56 5.03 .53-03	-.16 4.56 .64-03	.13 5.29 .53-03	2.28 5.31 .31-03	2.48 6.15 .13-03	2.93 5.85 .36-04	3.08 5.50 .71-05
-3.43 6.23 .36-04	-2.20 5.46 .18-03	-.96 5.28 .64-03	.14 4.90 .16-02	-.04 4.09 .27-02	1.39 3.74 .32-02	1.04 4.06 .27-02	.90 4.89 .16-02	2.23 5.51 .64-03	2.50 5.46 .18-03	3.39 5.18 .36-04
-4.22 3.68 .13-03	-3.23 3.64 .64-03	.44 3.43 .22-02	-.09 3.43 .55-02	1.10 2.88 .95-02	.76 3.37 .11-01	1.23 3.19 .95-02	.99 3.69 .55-02	1.85 4.45 .22-02	2.71 4.96 .64-03	3.34 4.96 .13-03
-4.05 .74 .31-03	-1.04 -.01 .16-02	-2.07 1.02 .55-02	2.52 .90 .14-01	.87 .98 .23-01	.40 1.34 .28-01	1.78 1.09 .23-01	1.84 1.96 .14-01	2.14 3.04 .55-02	2.26 3.29 .16-02	2.23 3.51 .31-03
-2.88 -2.92 .53-03	-2.02 -2.28 .27-02	.15 -2.10 .95-02	-.39 -1.48 .23-01	.76 -1.03 .40-01	2.48 -.52 .48-01	1.58 .30 .40-01	1.87 .22 .23-01	1.20 .97 .95-02	2.07 1.46 .27-02	4.07 1.71 .53-03
-7.35 -3.97 .64-03	-3.65 -4.06 .32-02	-1.41 -3.03 .11-01	-.28 -1.73 .28-01	1.04 -1.79 .48-01	.31 -1.05 .57-01	.80 -.63 .48-01	1.39 -.75 .28-01	2.16 -.24 .11-01	2.63 -.32 .32-02	3.08 .08 .64-03
-6.44 -2.70 .53-03	-2.98 -2.39 .27-02	-1.24 -1.80 .95-02	-1.19 -1.63 .23-01	-.10 -.94 .40-01	1.73 -1.24 .48-01	1.45 -.69 .40-01	1.83 -.75 .23-01	1.79 -1.38 .95-02	2.19 -1.53 .27-02	2.93 -1.71 .53-03
-7.39 -2.27 .31-03	-5.11 -2.15 .16-02	-2.89 -2.21 .55-02	-.47 -1.73 .14-01	.84 -1.78 .23-01	.88 -1.41 .28-01	2.01 -1.59 .23-01	1.28 -1.69 .14-01	2.86 -2.04 .55-02	2.94 -2.53 .16-02	2.93 -3.03 .31-03
-6.73 -2.26 .13-03	-5.57 -1.98 .64-03	-2.44 -2.70 .22-02	-.80 -2.96 .55-02	-.21 -2.45 .95-02	.97 -2.49 .11-01	1.50 -2.47 .95-02	3.10 -3.05 .55-02	2.26 -3.44 .22-02	2.57 -3.73 .64-03	3.53 -4.39 .13-03
-6.42 -2.79 .36-04	-4.71 -2.69 .18-03	-3.41 -4.26 .64-03	-1.58 -4.12 .16-02	-.11 -4.28 .27-02	.54 -4.23 .32-02	2.07 -4.38 .27-02	2.38 -4.73 .16-02	2.87 -5.15 .64-03	2.84 -5.45 .18-03	3.85 -5.79 .36-04
-6.40 -3.67 .71-05	-6.21 -4.01 .36-04	-2.09 -5.68 .13-03	-2.10 -5.92 .31-03	-1.08 -5.98 .53-03	.98 -6.94 .64-03	1.59 -6.70 .53-03	2.40 -6.67 .31-03	2.44 -7.04 .13-03	2.76 -7.04 .36-04	4.30 -7.27 .71-05

|◄ Unit ►|

X1M(1) = .876 units X2M(1) = 2.225 $units^2$ S = 1.638 units 1 unit = 25 ft

S = 41 ft

X1M(2) = -.633 units X2M(2) = 3.140 $units^2$ C.E.P. = 48 ft Previous Stage σ (assumed) = 42 ft

Fig. 18 (C) - High Resolution Radar Map of Boat Docks

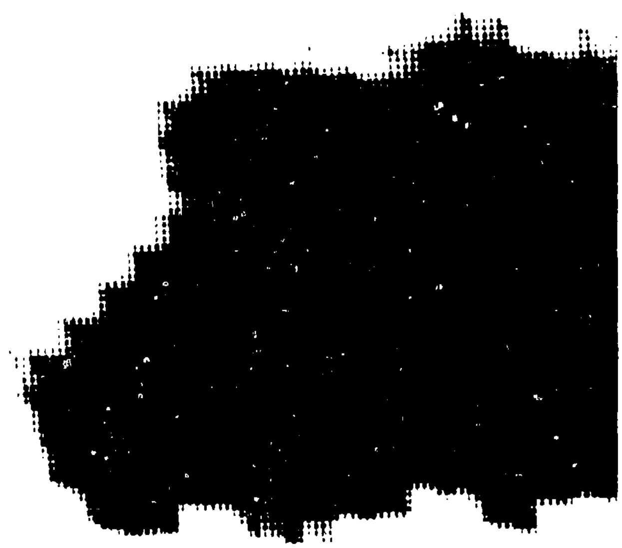

Fig. 19 (C) - High Resolution Radar Map (Low Altitude of Boat Dock

Fig. 20 (U) - Radiometric Map (Low Altitude) of Boat Dock

Table XIV (U) - Simulation Error Map (Low Altitude) for Boat Dock

-2.89 3.90 .71-05	-2.22 3.44 .36-04	-1.12 3.10 .13-03	-.42 2.67 .31-03	.18 2.51 .53-03	-.64 1.92 .64-03	-.23 1.80 .53-03	1.06 1.76 .31-03	1.42 1.73 .13-03	.67 1.30 .36-04	2.19 1.71 .71-05
-3.94 2.91 .36-04	-2.01 2.55 .18-03	-.67 2.40 .64-03	-1.36 1.63 .16-02	-.35 1.61 .27-02	-1.04 1.15 .32-02	.04 .89 .27-02	.30 .80 .16-02	-.27 .62 .64-03	.17 .30 .18-03	1.73 .83 .36-04
-3.69 2.06 .13-03	-2.45 1.78 .64-03	-1.14 1.50 .22-02	-.89 1.32 .55-02	-.47 .87 .95-02	-.22 .72 .11-01	-.56 .32 .95-02	-.92 .15 .55-02	.09 -.15 .22-02	.55 .04 .64-03	.38 -.18 .13-03
-3.46 1.56 .31-03	-1.39 1.41 .16-02	-1.33 1.02 .55-02	.65 1.42 .14-01	-.69 .63 .23-01	.83 .72 .28-01	-.95 .21 .23-01	-.06 .09 .14-01	-.45 -.29 .55-02	.46 -.16 .16-02	.00 -.67 .31-03
-1.69 1.74 .53-03	-1.25 1.25 .27-02	-.68 1.16 .95-02	.16 1.22 .23-01	1.17 1.23 .40-01	-.09 .67 .48-01	.05 .37 .40-01	-.12 .14 .23-01	.76 .23 .95-02	.24 -.32 .27-02	.31 -.82 .53-03
-2.73 1.45 .64-03	-2.02 1.22 .32-02	.22 1.22 .11-01	.90 1.29 .28-01	.34 .99 .48-01	.26 .68 .57-01	.65 .49 .48-01	.73 .13 .28-01	.33 .16 .11-01	-.80 -.99 .32-02	1.19 -.85 .64-03
-4.00 .88 .53-03	-.94 .82 .27-02	-.04 1.00 .95-02	-.07 .68 .23-01	1.21 .55 .40-01	.89 .29 .48-01	.86 -.17 .40-01	-.76 -.54 .23-01	.57 -.68 .95-02	1.23 -1.32 .27-02	.48 -1.61 .53-03
-2.96 -.06 .31-03	-1.89 .21 .16-02	-.56 .22 .55-02	.42 .38 .14-01	.73 .15 .23-01	1.54 .09 .28-01	-.30 -.28 .23-01	1.22 -.47 .14-01	1.11 -.67 .55-02	1.65 -1.16 .16-02	1.61 -1.74 .31-03
-3.75 -1.14 .13-03	-1.01 -.62 .64-03	-.66 -.46 .22-02	.55 -.31 .55-02	1.20 -.21 .95-02	.47 -.38 .11-01	1.90 -.31 .95-02	1.10 -.55 .55-02	1.49 -.64 .22-02	1.98 -.90 .64-03	1.73 -1.70 .13-03
-3.34 -2.26 .36-04	-2.74 -1.80 .18-03	-.51 -1.40 .64-03	.15 -1.10 .16-02	.79 -.90 .27-02	1.50 -.77 .32-02	.81 -.82 .27-02	2.22 -.89 .16-02	1.86 -.86 .64-03	2.35 -1.07 .18-03	3.69 -1.46 .36-04
-4.71 -3.67 .71-05	-2.04 -2.90 .36-04	-1.52 -2.44 .13-03	-.15 -2.12 .31-03	.74 -1.84 .53-03	.71 -1.70 .64-03	1.61 -1.49 .53-03	1.30 -1.60 .31-03	2.47 -1.61 .13-03	2.82 -1.53 .36-04	3.10 -1.91 .71-05

|◄ 25 ft ►|

X1M(1) = .344 units X2M(1) = .652 units^2 S = .796 units 1 unit = 25 ft

S = 19 ft

X1M(2) = .423 units X2M(2) = .530 units^2 C.E.P. = 23 ft Previous Stage σ (assumed) = 42 ft

- o Table VI is a sample graphic display of digitized radiometric densities presented for illustration only. This display was prepared in the same way as that used to prepare the displays based on the radar data.

- o Table VII presents the real and imaginary components as defined by 1 for the position operator for the digitized radar densities in Table III. For example, in Table VII, 1* corresponds to the real and imaginary components of a_1 given in 1 .

- o Tables VIII, IX, X, XI, XII, XIII, XIV are simulation error maps of the 11 x 11 matrix used in the correlation calculations.

(U) As an aid in understanding the simulation error maps, reference should be made to Table VIII. Position 1 refers to the first element of the 11 x 11 correlation matrix. If the missile were at Position 1 at the time of the correlation, its error in location would be calculated in the x coordinate as -2.15 units and in the y-coordinate as 4.97 units. For the high altitude correlation, one unit equals 300 ft. Assuming normally distributed midcourse guidance errors with a CEP of 500 ft., the probability that the missile would be at Position 1 at the time of the correlation is $.71 \times 10^{-5}$. The locations and positioning probabilities for the other elements of the 11 x 11 correlation matrix are also given in Table VIII. The other parameters listed in the simulation error maps are defined below.

X1M (1) = 1st moment about the origin in the x direction

$$= \text{mean (x direction)}$$

$$= \sum_{i=1}^{121} X_i P_i$$

X2M (1) = 2nd moment about the origin in the x direction

$$= \sum_{i=1}^{121} X_i^2 P_i$$

X1M (2) = 1st moment about the origin in the y direction

$$= \sum_{i=1}^{121} Y^2 i P_i$$

X2M (2) = 2nd moment about the origin in the y direction

$$= \sum_{i=1}^{121} Y_i^2 P_i$$

$$S = \left[\frac{X2M(1) + X2M(2)}{2} \right]^{1/2}$$

$$C.E.P. = S/.8493$$

The circled position in Table VIII represents the origin of the correlation matrix.

(U) Tables VIII, IX, and X represent the simulation error maps for a missile trajectory in which 3 correlations are performed before missile impact. As seen in Table VIII, the missile position distribution has a S equal to 263 ft. after the 1st correlation. In order to have a probability (3σ) of .997 that the area corresponding to the reference map will be viewed by the sensor at medium altitude a S of 208 ft. is needed. Therefore, another correlation should be performed between high and medium altitude. One or two additional correlations are also needed between the medium and low altitudes. A S of 118 ft. was determined after correlation at mid-altitude, but a S of 35 ft. is required to put the system into the correct viewing area at low altitude.

(U) Therefore, in order to reduce midcourse error to a C.E.P. of 24 ft. 5 or 6 correlations are needed for Bridge #1. It may be possible to reduce this number to 4 correlations by carefully selecting the altitudes at which the correlations are performed. This procedure should be the topic of a future study. For the remaining targets, the correlations were performed only at low altitude. It was assumed with a probability (3σ) of .997 that the area which corresponded to the reference map containing the aim point was viewed by the sensor at low altitude.

7.0 Conclusions

(C) Assuming midcourse errors of σ = 500 ft. along and cross track and for target images containing large areas of high contrast like bridges with land water boundaries or airfields with runway boundaries, C.E.P.'s of less than 26 ft. were achieved. A C.E.P. of

48 ft. was achieved for one target of medium contrast, a railroad complex, at low altitude. This result however, is inconclusive because the railroad car positions appear to have changed between radar and radiometric flights making correlation extremely difficult. Five or six correlations were necessary to obtain convergence for a bridge in an area of good contrast. It may be possible to reduce the numbers of correlations to four by choosing different altitudes of correlation.

(C) The results of this study can only establish ballpark values for miss errors generated by the map matching technique since sufficient data has not been processed for a valid statistical analysis. Therefore, it is recommended that simulations of the entire terminal sequence be carried out for several targets of high, medium, and low contrast backgrounds. The effects of missile airframe steering and response errors should also be included. The correlation technique should also be applied to images from other terminal sensors. In particular, it should be applied to images obtained from low-resolution radar.

References (U)

(1) Wilson, J. D., "NRL Report 6684, A Multiple Sensor Digital Map Matching Technique," July 19, 1968 (Confidential)

(2) Steigerwalt, O. I., Final Report Contract N00014-66-00276, Sperry Microwave Electronics Division of Sperry Rand Corporation, "Application of Vector Space Methods," September 1967 (Confidential)

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13. ABSTRACT

(C) A terminal guidance map-matching technique was evaluated on a digital computer. Imagery of known quality, from flights of the AN/APQ-97 radar and AN/AAR-33 microwave radiometer, were correlated for targets of varying contrast levels.

(C) System performance, characterized by a C.E.P. of 26 ft. excluding missile airframe steering and response errors, was obtained on targets having large areas with high contrast, such as bridges, airfields, and boatdocks. Examples of these target classes were studied at the lowest altitude guidance stage, which determines impact C.E.P. One bridge was studied at low, middle, and high altitudes to simulate major portions of the entire terminal sequence of repeated position fixing and course correction.

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